# FURTHER STUDIES ON TRANSPLANTATION OF VESSELS AND ORGANS.[1]

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(*Read, November 6, 1908.*)

It is known that tissues can be removed from an animal, transplanted into another animal and live normally in the body of their new owner. The transplantation of anatomical structures has already been, and will be again in the future, used in human surgery. For instance, an excellent method of treating an aneurism of the femoral artery would be the extirpation of the diseased part and its replacement by a piece of artery of same caliber. This new artery cannot be taken from an animal and grafted on man, for the serum of an animal is toxic for the cells of an animal of different species. A dog's vessel transplanted on man could possibly perform its arterial functions, but the histological structure of its wall would be deeply modified and accidents could occur. It is probable that arteries from anthropoid ape would be of safer use, because man and ape are closely related from a zoölogical standpoint. But this would be exceedingly expensive and not practical. It will be safer and simpler to graft on man vessels taken from another man. The vessels can be extirpated from an amputated limb or from the body of a criminal or of a man killed by accident. But it is sure that these cases will not present themselves at the time convenient for the surgeon and his patient. Therefore, it is important to find a method to store human vessels during the period which will elapse between their extirpation and their graft on the patient. With this view, I have attempted to preserve arteries in a condition of latent life, in order that, after having spent several days or several weeks outside of the body, they can be transplanted successfully.

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Before describing the method which renders possible the preservation of arteries, I shall briefly summarize some of the results obtained at the Rockefeller Institute in the transplantation of blood vessels and organs. These operations became possible as soon as a practical method of uniting blood vessels was found. Success in transplanting organs is direct function of the circulation. The circulation cannot be immediately reëstablished but by the sewing of the vessels of the organ to those of the host. The sewing of vessels is today a very easy operation. Some years ago, while I was working at the University of Lyons, I found a method of uniting severed arteries or veins, which gave excellent results. This method was progressively improved in such a manner that it is practically always successful. The vessels heal very quickly and no coagulation of the blood occurs when the operation is aseptic and the union of the vascular ends accurate. The scar of the severed vessels is, in many cases, so small that after a few months it is hardly discernible. On a renal vein examined a little over two months after the sewing, it was impossible to localize exactly the position of the anastomosis. The anastomosis of the renal artery was represented only by an indistinct line crossing the intima. Twelve months after the anastomosis of a carotid artery, the anatomical specimen was removed and examined. After longitudinal incision of the wall, no scar was seen on the intima, there was no modification of the caliber. But, in one small point, the vessel had lost part of its elasticity and it permitted to localize approximately the anastomosis. The results are permanent. Two and three years after the operation, the circulation through the anastomosis remains normal. It must be known also that, if the method is not correctly applied, or a fault of technique, even very slight, is made, thrombosis may occur. Success depends much less on the way of handling the needles or passing the threads than on the knowledge of the causes which are able to produce thrombosis and their removal. On human beings, this method has already been successfully used by American and European surgeons, and on animals, it has permitted to perform the transplantation of blood vessels, organs and limbs.

The graft of a segment of artery on an artery of another animal of the same species is ordinarily successful when the vessels are of sufficient caliber. After a few months, the transplanted segment assumes exactly the same appearance as the normal vessel. The carotid of a dog was examined three months after the graft of an arterial segment. The transplanted segment was exactly similar to the other parts of the artery. There was no modification of caliber. The elasticity was normal. The only evidence of the operation was two whitish transverse lines on the intima. The remote results are excellent. A dog, into whose aorta a segment of aorta from another dog had been transplanted, was living and in good health nine months after the operation and the femoral pulse was normal. The transplantation of arteries has already been attempted in human surgery by Pierre Delbet in the treatment of aneurism. When a large artery is wounded and partially destroyed, or when a tumor adherent to the main vessels of a limb renders necessary the extirpation of these vessels, the substitution of a new piece of artery to the removed part would prevent the occurrence of gangrene.

The graft of an artery of an animal into an animal of different species is often successful if the animals are closely related. I transplanted several times segments of dog's carotid arteries on the abdominal aorta of cats with excellent functional results. Nevertheless, these results cannot be compared with those obtained in transplantation between animals of same species. Sometimes the lumen becomes dilated, or even a fusiform aneurism can be found. Even when the functions of the transplanted segment are perfect, its wall undergoes marked histological changes. The elastic framework disappears and progressively the muscular fibers are resorbed. After a few months, they have practically disappeared. The vessel is then composed mainly of connective tissue.

Veins can easily be grafted on arteries. I performed several times the transplantation of the vena cava on the aorta, on dogs and on cats, with excellent results. A segment of vein transplanted into an artery undergoes immediately very marked changes. The wall, which is very thin, becomes thicker and stronger. The lumen is often dilated, but no aneurism has ever been observed. On the contrary, the vein reacts against the increased blood pressure by thickening its wall. The thickening is due to an hyperplasy of the muscular cells and an hypertrophy of the adventitia. There is also a very large increase of the interstitial connective tissue of the media. The venous wall becomes as strong as the arterial wall. The function has created the organ. Therefore, veins can act as a substitute for arteries. This is of practical importance in human surgery, for on the patient himself an abundant supply of vein can always be found.

The organs, kidneys, spleen, or thyroid gland, for instance, can be transplanted from an animal to another animal and their circulation immediately reëstablished by suture of the blood vessels to those of their host. Two methods are used—the simple transplantation, and the transplantation in mass. The simple transplantation consists of dissecting the organ, cutting its vessels, and uniting these vessels directly to those of the host. In the transplantation in mass, the organ is extirpated, together with the surrounding tissues and organs, its nerves, vessels and the main vessels of the region. After transplantation, the anastomoses are not made on the vessels of the organ themselves, but on the main vessels of the anatomical region. The transplantation in mass of the kidneys has been performed on cats. It consists of extirpating from a first animal both kidneys, their vessels and the corresponding segments of the aorta and vena cava, their nerves and nervous ganglia, their ureters and the corresponding part of the bladder; of placing these anatomic specimens into the abdominal cavity of a second animal whose kidneys have been previously resected and the aorta and vena cava cut transversely; and of suturing the vascular segments between the ends of the aorta and vena cava, and of grafting the flap of bladder onto the bladder of the host. In every case the reëstablishment of the renal functions was observed. These functions were determined by the character of the urine and the general condition of the animals.

The secretion of urine often begins as soon as the arterial circulation is reëstablished. In some cases the amount of urine during the first twenty-four hours was more than 100 c.c. However, a cat urinated only 25 c.c. during the first twenty-four hours; the second day the amount of urine passed was only 16 c.c.; this urine was highly concentrated and contained much urea. Every cat urinated abundantly every day, but the animals presented sooner or later some complication, which modified in some measure the renal functions. As is to be expected after an operation as complex as the transplantation in mass, various accidents occurred; hydronephrosis, intestinal compression by peritoneal adhesions, volvulus, phlegmon, puerperal infection, compression of the renal veins by organized hematoma of the connective tissue, which were the direct or indirect causes of death in these animals. However, in two experiments the functions of the kidneys seem to have been for a certain time almost completely normal. The color of the urine was yellow, generally, or often less dark than the normal urine of the cat. Its reaction was acid. Its quantity for twenty-four hours oscillated between 120 and 160 c.c., but it might be, exceptionally, 25 and even 15 c.c., or in another case, 215 or 255 c.c. for twenty-four hours. The density was very far from constant; generally it oscillated between 1.018 and 1.030, going sometimes as high as 1.035 and 1.051. Among the abnormal constituents of the urine the presence of albumin only has been looked for. In some cases there was a little albumin during the first days, ranging from 0.50 to 0.25 for 1,000 c.c. In other cases the albumin disappeared about one week after the operation.

The general condition of the animal can be used, in some measure, to indicate the perfection of the urinary elimination. As long as no complications were present the animals lived as normal cats do, without presenting any symptoms which could be considered as produced by renal insufficiency. When general complications occurred the cats reacted against them in normal ways. In one case, the animal was in apparently normal condition four days after the operation. She walked about the room, played and ate a great deal of raw meat. Her condition remained excellent for several weeks. Twenty days after the operation she was in good health, had glossy hair, was very fat, ate with appetite all kinds of food and urinated normally. There was, however, albumin in the urine, and slow and progressive enlargement of the kidneys took place, which showed that she was not in an entirely normal condition. It remained in excellent health until the twenty-ninth day after the operation. Then gastro-intestinal symptoms appeared, and death occurred on the thirty-first day after the operation.

In another experiment the animal was a female cat which had lived in the laboratory for several months. She was in excellent condition when she was operated on and recovered very quickly from the operation. Her life went on just the same as before. The kidneys were movable and small. She looked in excellent health and lived as a normal cat. On the eighteenth day after the transplantation albumin appeared in the urine and a direct examination of the kidneys was made to ascertain the cause. The general condition was little affected by the operation and the albumin disappeared on the twenty-first day, but reappeared again a little later. On the thirty-fifth day the animal was very weak and emaciated. She died on the thirty-sixth day of acute calcification of the arteries.

These results show that the functions of the kidneys reëstablished themselves after the transplantation. Since an animal can live in an apparently prosperous condition of health fifteen or twenty-five days and more, after a double nephrectomy, and eliminate each twenty-four hours from 120 to 160 c.c. of urine through the new kidneys, it is certain that the functions of the transplanted organs are efficient.

The "simple transplantation" of the kidneys consists of dissecting a kidney, cutting the renal vessels and ureter a few centimeters below the hilus, implanting the organ on the same or another animal, and of anastomosing its vessels to the renal vessels of the host. I performed the double nephrectomy and the replantation of one kidney in five dogs. The secretion of the urine remained normal as long as no ureteral complication occurred. The conditions of the kidneys were excellent. A little more than two months after the operation, the location of the anastomoses of the renal vein could not be detected. The anastomosis of the renal artery was seen as a small and indistinct line on the intima.

The remote results of this operation are excellent. On February 6, 1908, the left kidney of a middle-sized bitch was extirpated, perfused with Locke's solution and put into a jar of Locke's solution at the temperature of the laboratory. The ends of the vessel were prepared for anastomoses, and afterward the kidney was replaced into the abdominal cavity. The circulation was reëstablished after suture of the vessels and the ends of the ureter united. The animal made an uneventful recovery. Fifteen days afterward the right kidney was extirpated. The animal remained in perfect health. The urine did not contain any albumin. It is generally of low density. Today the animal is in perfect condition. (Fig. 1.)

FIG. 1. The dog, who is jumping, underwent nine months ago a double nephrectomy and replantation of one kidney.

This observation demonstrated definitely that an animal can live in normal condition after both kidneys have been extirpated and one replaced. It removes also, without need of further discussion, the objections of the experimenters who claim that the section of the renal nervés, the temporary suppression of the renal circulation or the perfusion of the kidneys produce necessarily dangerous and even fatal lesions of this organ.

By using the method of transplantation in mass it becomes possible to perform the transplantation of a whole anatomic region, with its main artery and vein. From a first dog, the right part of the scalp and the auricle were extirpated in one mass wtih the cartilaginous portion of the auditory canal cut close to the skull, the connective tissue and the glands of the retro-maxillaris space, the tissues of the carotid region, and the upper portions of the external jugular vein and of the common carotid artery. On a second dog the auricle and a portion of the scalp was extirpated and the right part of the neck opened through a longitudinal incision. The anatomic specimen was then placed close to the wound, and the peripheral end of the carotid artery and of the jugular vein united to the central end of the corresponding vessels of the host, at the level of the middle part of the neck. The circulation was then reëstablished. Then the neck was closed by two rows of suture. A few minutes after the establishment of the circulation the ear and the scalp assumed their normal appearance. The new ear was fixed by circular suture of its cartilaginous canal to the cartilaginous canal of the host. The auricular muscles were sutured and the operation completed by continuous catgut suture of the skin without drainage.

Three weeks after the operation the auricle and the transplanted tissues were in normal condition. The temperature of both auricles, normal and transplanted, were about the same. The transplanted ear was as thin and glossy as the normal one. Except for the difference of color, it could not have been seen that the ear did not belong to the dog.

The transplantation of a limb from one animal to another of the same species is a problem very much simpler than the transplantation of a gland. In April, 1907, I found that a thigh, extirpated from the fresh cadaver of a dog, and transplanted onto another dog, could begin to heal in a very satisfactory manner. One year after, by using more careful asepsis in the transplantation of the leg from one fox terrier to another, I observed union by first intention of the new leg to its host.

A white, middle-aged male fox terrier was etherized and the left leg cut just below the knee. The limb was perfused with Locke's solution, wrapped in a greased silk towel and kept on a table at the temperature of the laboratory. A white, young female fox terrier was etherized. She was of the same size and shape as the first dog. Her nails and bones were very slightly smaller. The leg was amputated circularly just below the knee. The new leg was immediately fixed to the central end of the tibia of the host by an Elsberg's aluminum splint. The muscles, nerves and femoral vessels were united to the corresponding parts of the host, and the circulation reëstablished. A small exploratory incision was made between the second and third toes. Hemorrhage of red blood occurred. The animal recovered quickly and remained in normal condition. The temperature of the new foot was at first higher than that of the normal one. It was also edematous. After a few days the edema disappeared and the foot had exactly the same appearance as the normal one. The temperature went slightly down. There was only a difference of one tenth of a degree centigrade between the normal and the new foot.

Fifteen days after the operation the new leg was perfectly healed by first intention, but the bones were not very strongly united. The Elsberg splint had broken and the tibia was a little incurved. The exploratory incision of the foot, although having been slightly infected, was completely cicatrized. The new leg had the same appearance as the normal one. The animal was in good condition, but coughed a little. At this time several other dogs died of broncho-pneumonia. The animal became sick. Twenty days after the operation her condition became worse and a marked dyspnea appeared. The dog died on the twenty-second day after the operation. Postmortem examination showed a double diffuse bronchopneumonia. The new leg was perfectly healed; with linear cutaneous scars. Its appearance was exactly the same as the normal leg. The bones were strongly united by a fibrous callus. The exploratory incision of the foot had healed without visible scar.

This experiment is the first example of successful grafting of a new limb on an animal. It demonstrates that the leg, in spite of the change of owner, remains normal. If further experiments show that the functions of the transplanted limb are normally reëstablished, it will be permissible to try on man the transplantation of limbs, or segments of limbs, taken from an amputated limb, or from the body of a man killed by accident.

All these experiments show that the remote results of the transplantation of fresh vessels can be perfect, that transplanted kidneys functionate, that an animal having undergone a double nephrectomy and the transplantation of both kidneys from another animal can live normally for a few weeks, and that an animal which has undergone a double nephrectomy and the graft of one of his own kidneys can recover completely and live in perfect health. Finally, it has been demonstrated that a leg extirpated from a dog and substituted for the corresponding leg of another dog heals normally.

Since the experimental transplantation of arteries are permanently successful, it is permissible to use this method in human surgery; for instance, in treating aneurisms as it has been already tried by Delbet in Paris. The era of these operations being opened, the attempt of preserving blood vessels outside of the body in a condition of latent life was made with the view of rendering these operations more practicable.

The length of the period which elapses between the extirpation of a tissue, and the reëstablishment of its circulation after transplantation, is an important factor of success or failure. The result of the graft depends entirely on the condition of the tissues at the time of the reëstablishment of the circulation. They must still be alive; although apparently dead. If the tissues are really dead, the graft is completely unsuccessful. There are two kinds of death, general death or death of the whole organism, and elemental death or death of the tissues and organs. It is impossible to give a definition of general death. Everybody understands what it means. Nevertheless, we are as ignorant about it as about life. General death can occur suddenly, while elemental death is a slow process. A man, for instance, is stabbed through the heart and killed. His personality has disappeared. He is dead. However, all the organs and tissues, which compose the body, are still living. The life of every tissue and organ of the body could go on if a proper circulation was given back to them. If it were possible to transplant immediately after death the tissues and organs, which compose this body, into other human organisms, no elemental death would occur, and all the constituent parts of the body would continue to live. The man, however, would be dead, for his personality would have disappeared. In this case, general death can be defined as the rupture of the contract of association between the tissues and organs of the organism by failure of one of the partners, the heart. Therefore, general death is very different from elemental death. It is merely the starting point of the disintegrative phenomena which lead to elemental death.

Immediately after general death, elemental death begins. It is a complex and slow process which progressively destroys the living matter. We cannot know directly whether or not a tissue is living and by what chemical or physical peculiarities a living being differs from its corpse. There is no reagent of life. Living matter, in a condition of non-manifested life, is apparently similar to non-living matter. We perceive life only through its manifestations. Our ignorance renders for us unmanifested life similar to death. If seeds or microbes are placed in physico-chemical conditions, where manifested life is impossible, living matter canot be distinguished from dead matter. What is the difference between a dead seed and the seed which will produce a large tree? We do not know. Between a vessel which will live normally after transplantation, and another one which will undergo deep microscopical lesions, there is no morphological difference. We know merely that, immediately after general death, the tissues are still alive, because they manifest life if they are given back their normal circulation. We know also that some time after general death they die, because they are not able to manifest life again, even when replaced in normal physiological condition. Between the death of the organism and the elemental death there is a period where the tissues are progressively invaded by cadaveric disintegration. At the beginning, the cadaveric changes are slight, and the tissues can recover if placed back into normal condition. Later, irreversible changes take place and elemental death, that is, destruction of the living matter, occurs.

The duration of this period intermediate between death of the organism and elemental death is longer or shorter, according to the nature of the tissue. The cerebral substance disintegrates so quickly that, after a few minutes of complete anemia, irreparable lesions take place. The spleen, liver and kidneys are also rapidly destroyed. On the contrary, the anatomical structures which compose a limb are very strong and can overcome for a long time the cadaveric processes. The different parts of the same organ do not present similar resistancy to cadaveric disintegration. Among the anatomical components of renal substance, the cells of the secretory tubules are extremely delicate and may present marked morphological changes a short time after death. The cells of the excretory tubuli are stronger. The glomeruli are still more resistant. It may happen that the epithelial cells are already dead, while the glomeruli and the vessels are still living. The vascular endothelium seems to be the "ultimum moriens" of the organ, according to Wells. The vessels, which are the necessary condition of life of organs, are also the part of the organs which resists longer the disintegrative processes. The elements which compose the wall of an artery differ widely in resistancy. The muscular fibers die first. Immediately after the stopping of the circulation, all the elements of the vascular wall are alive. If the transplantation is performed at this moment, the artery lives in the body of its host and keeps its normal constitution. If the transplantation is performed a little later, when the muscular fibers are already dead, the wall of the artery will be composed mainly of connective and elastic tissue, and the muscular fibers will disappear. If the artery is completely dead when the transplantation is made, its wall will be composed of amorphous substance, around which the organism will create an envelope of dense connective tissue.

Elemental death is brought about by microbian and autolytic enzymes. Immediately after general death, the microörganisms from the digestive tract diffuse through the body and their ferments begin to destroy the tissues. At the same time, the autolytic ferments, which are not any longer held in check by the serum, contribute also to the disintegration of the organs. This destructive process is increased or retarded by the causes which activate or retard the enzymotic actions, and the multiplication of the microorganisms. For instance, the rate of cadaveric disintegration, which is very rapid at 35° or 40° C., becomes very slow at + 1° or + 2° C. It is completely stopped by desiccation of the tissues. The preservation of the tissues in the serum of the same animal will also retard very much the organic destruction.

The occurrence of cadaveric changes in tissues, which will be used for transplantation, must be prevented. This can be attained in two different manners: by stopping completely the chemical activities of the tissue, or merely by retarding so much the evolution of autolytic disintegration that, after a few days or a few weeks, the lesions are so small that they are not dangerous.

The first method would be ideal. The tissue, being in a condition of chemical indifference, could be preserved theoretically for an indefinite period. There are many instances of this form of latent life in the animal kingdom. Two centuries ago, Loevenhoeck obtained the resurrection of *Milnesium tardigradum,* which had been completely dried for a long time, by moistening it with water. In 1840, Doyere studied also the peculiarities of latent life of *Milnesium tardigradum.* He dried completely a few of these animals, heated them at a temperature of 100° C., and, after having humidified them, observed that they lived again. These observations are very important because *Milnesium tardigradum* is highly organized and contains muscular fibers, nerves, nervous ganglia, etc. Paul Bert, in several famous experiments, attempted to preserve tissues of mammals in a condition of latent life. One of those experiments consisted of cutting the tail of a rat, drying it in vaccum, and submitting it to a temperature of + 100° C. The tail was afterwards transplanted onto another rat. It was observed that the dimensions of the tail grew larger, that its vessels united to the vessels of the host and that the bone marrow underwent fibrous degeneration. It showed that the heated and dried tail could live again. I attempted to preserve arteries in latent life by a similar method. Carotid arteries from dogs were extirpated and placed in sealed glass tubes, part of which were filled with calcium chloride. Within a few hours, the arteries became yellow brown, shrank and looked like pieces of catgut. One tube was heated for twelve minutes at + 100°. When, after several days, the dried vessels were put into Locke's solution, they took back their water and assumed again their normal color, size and consistency. Two of them were transplanted onto the carotid arteries of dogs. It was found that they could perform normally their functions. Two weeks after the operation, one of the vessels was examined. The circulation was normal. The transplanted segment looked very much like the other parts of the carotid. It was covered by a normal connective tissue sheath. The wall was of same color and thickness as the wall of the normal carotid. Its consistency was a little harder. Nevertheless, it was found, by microscopical examination, that this wall was composed of an elastic framework and amorphous material surrounded by a new wall of connective tissue. The vessel was dead. The death of the vessel was perhaps due more to the way in which the desiccation was done than to the desiccation itself. With a better technique, results similar to those of Paul Bert could possibly be obtained. Actually, this method is dangerous because the artery is not any longer a living structure, but merely a foreign body, as a piece of rubber tubing or an artery preserved in formalin or killed by heating.

The second method of preserving arteries, outside of the body, consists in lowering the power of the microbian and autolytic enzymes, by keeping the tissues at a low temperature. This method cannot suspend, for an indefinite time, the occurrence of elemental death. It increases only the length of the period during which the cadaveric changes are slight and not able to interfere with a complete, or almost complete, recovery of the artery after transplantation. If a vessel is extirpated aseptically, placed in a sterilized sealed tube and kept in a refrigerator just above the freezing point, it can be preserved for a long time in good condition. From a surgical standpoint, it is sufficient that the vessels are kept safely for a few days outside of the body before being transplanted. Nevertheless, it is far from perfect. The ideal method would be certainly to place the tissues in a condition of latent life, as is possible for *Milnesium tardigradum* and other organisms.

The technique that I use is very far from being original. The vessels are merely preserved in cold storage as are commonly eggs, or chickens, or vegetables. They are removed from a living or a dead animal soon after death, perfused and washed with Locke's solution and placed in sterilized glass tubes, the atmosphere of which is moistened with a few drops of water. The tubes are immediately


FIG. 1.

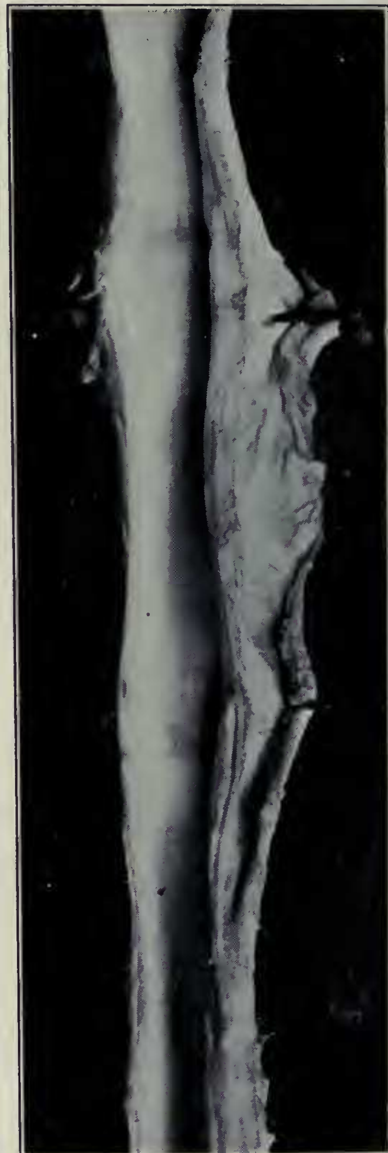

FIG. 2.

FIG. 1. Segment of artery preserved in a sealed sterilized tube.

FIG. 2. Segment of artery preserved for twenty two days in cold storage. Six months after transplantation.

sealed. (Plate VII, Fig. 1.) Sometimes, the arteries are put in a fluid. A few vessels have been preserved in isotonic sodium chloride solution. The result was unsatisfactory; for the muscular fibers of the artery were killed in twenty-four hours. The results obtained with Locke's solution were much better. However, a still better method would consist in keeping the vessels in serum of an animal of the same species or in inactivated serum of an animal of different species. The serum is more exactly isotonic for the tissues than Locke's solution; it is slightly bactericidal, and it contains antibodies for the autolytic ferments of the cells. I performed once only the transplantation of a segment of dog's carotid, preserved in dog's serum for forty-eight hours. Fifteen days after the transplantation, the vessel was examined and found in a perfect microscopical condition.

The sealed tubes containing the arterial segments are put into a thick-walled ice-box, the temperature of which remains constantly between 0 and + 1° C. The temperature must not go down below 0° C. When the vessels have been frozen, the wall presents soon after the transplantation marked microscopical lesions. If the temperature is too high, and the operation not thoroughly aseptic, microbian colonies may settle in the wall of the vessels. Obliteration or development of fusiform aneurism are the consequence of these faults of technique. When the operation has been correctly performed, the artery keeps its normal appearance for a long time. After several weeks, its color and consistency are generally normal. The wall is a little softer and the vessel flattens itself more easily. After six, seven and even ten months, the macroscopical appearance of the vessel is not markedly modified. Sometimes it looks completely normal. From a microscopical standpoint, the condition of the arteries is very variable. In some cases, the nuclei of the muscular fibers are modified. In other cases they are absolutely normal. A section of a pig's carotid artery, preserved in a sealed tube with a few drops of Locke's solution from April to November, 1908, was entirely normal. It looked as if it had been extirpated from the animal a few moments before being fixed in Zenker's fluid, while it had been preserved for six months outside of the body.

A few minutes before the transplantation, the tube is removed from the ice-box and broken. The vessel is removed from the tube, put in a jar of Locke's solution at the temperature of the laboratory, thoroughly washed and placed in warm vaseline. Afterward, the vaseline is expressed from its lumen, and the segment grafted onto the artery of the host. As soon as the circulation is established through the artery of the host, the transplanted segment, which is white, takes back immediately its normal color and becomes almost similar to the other parts of the artery. Sometimes the small vessels of the adventitia appear neatly injected with blood. In segments of carotid artery, preserved for eight and eleven months in cold storage and grafted on the carotid of a dog, the vasa vasorum were seen full of blood as soon as the circulation was reëstablished.

The results of the transplantation of arteries, preserved in cold storage, are generally excellent from a functional standpoint, even if the vessel has been kept for one or two months outside of the body. But, from an anatomical standpoint, the microscopical constitution of the vessel is markedly modified when it has spent a long time in cold storage. The duration of the period during which a vessel can be preserved without occurrence of any lesion, is not exactly determined. However, it seems that an artery, preserved for more than eight days in cold storage, undergoes always, after transplantation, a degeneration of its muscular fibers, while the other parts of the vessel seem to remain normal. Several times a perfect histological condition of the transplanted artery was observed. A piece of carotid artery from a dog was put in a sealed tube with a few drops of Locke's solution and, two days afterward, transplanted onto the carotid artery of another dog. Two weeks after the operation, the neck of the dog was reopened. The circulation through the carotid was normal. The transplanted segment looked like the other parts of the carotid. It was resected and examined histologically. The adventitia was thickened and contained several small vessels. The media was normal. The nuclei of the muscular fibers were found entirely similar to those of a normal artery. The intima was well preserved and slightly thickened. This observation shows, evidently, that a vessel can be preserevd in cold storage and live again normally when transplanted. It is not a dead, but a living artery, with all its normal anatomical elements.

Thus, the vessel, while in cold storage, was in a condition of unmanifested life.

The behavior of a vessel, transplanted after having been killed, by formalin or by heating at 80° C., is different. Often its appearance is normal, from a gross anatomical standpoint. Nevertheless, a few days after transplantation, its microscopical constitution is deeply modified. Its wall is composed of an amorphous material where no nuclei can be observed, but where the elastic framework still is visible, although very modified in its shape. The wall is surrounded by a layer of connective tissue produced doubtless by the host. A dead vessel is merely a foreign body, which would progressively be resorbed and replaced by connective tissue. Thrombosis frequently occurs after this kind of transplantation and its use is dangerous from a clinical standpoint. On the contrary, a vessel, preserved for a few days in a condition of latent life, is still a living structure when it is transplanted. Its use is as safe as that of a fresh artery.

In all the cases where the vessels spent more than eight days in the ice-box, the muscular fibers of the media disappeared a few days after transplantation. Nevertheless, the anatomical results were often so perfect that, after a few months, the location of the transplanted segment on the artery of the host was hardly discernible. On April 2, 1908, a piece of carotid, preserved for twenty-two days in cold storage, was transplanted on the carotid of a dog. On October 15, 1908, the neck was opened and the carotid dissected. It was not possible to find the location of the transplanted segment. After longitudinal opening of the carotids, the location of the anastomoses could be determined. (Plate VII, Fig. 2.) The result of the graft of a vessel which had spent seventy days in cold storage was as satisfactory. Six months after the operation a section was made through the middle part of the transplanted segment. The adventitia was normal and the intima thickened. The media was composed of elastic fibers which had retained their ordinary wavy appearance. All the muscular fibers had been destroyed.

The actual method failed to give positive results in the transplantation of arteries after several months in cold storage. Graft of arteries which had spent eight months outside of the body was attempted in two cases. Thrombosis occurred. The vessels were dead, and, in spite of their almost normal appearance, markedly disintegrated.

The remote results of the transplantations of preserved vessels are very satisfactory from a clinical standpoint. In November,

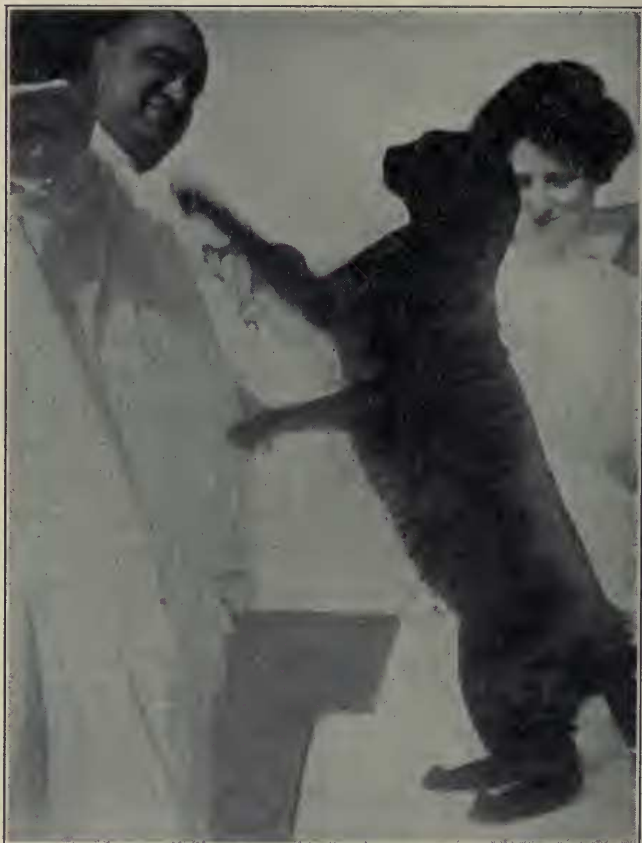

FIG. 2. Cat in which a segment of the abdominal aorta was replaced by a piece of dog's carotid.

1906, a segment of the abdominal aorta of a cat was extirpated and replaced by a piece of dog's carotid preserved in cold storage for twenty days. The animal remained in excellent health. After a few weeks, the abdomen was reopened and the transplanted artery